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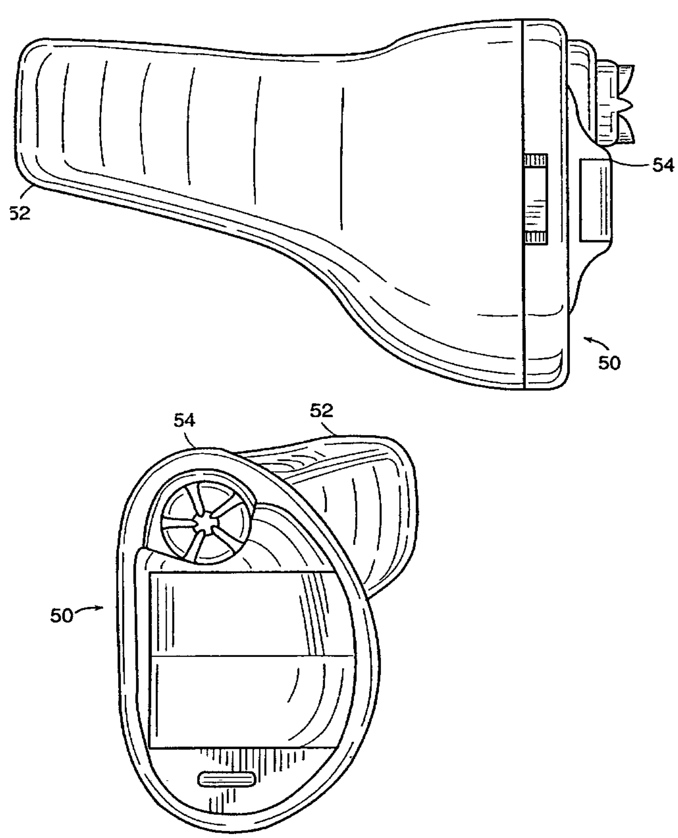
(54) Title: COCHLEAR IMPLANT SYSTEM PARTIALLY INSERTABLE IN THE EXTERNAL EAR

(57) Abstract: A cochlear implant system has a signal processor (50) that fits in the ear canal of a user. The signal processor (50) processes an acoustic signal present in the ear of the user to produce a representative radio signal. A power transmitter transmits an electrical power signal through the skin of the user. A cochlear implant receives the radio signal and the electrical power signal and produces for the auditory nerve of the user an electrical stimulation signal representative of the acoustic signal.



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COCHLEAR IMPLANT SYSTEM PARTIALLY INSERTABLE IN THE EXTERNAL EAR

Field of the Invention

The invention relates to a hearing prosthesis system using a cochlear implant.

Background Art

Deafness may be due to total sensorineural hearing loss. This is where the cochlea does not respond to sound waves, and therefore does not generate electrical signals for transmission to the cochlear nerves. An auditory prosthesis may use a suitable stimulation electrode arrangement capable of stimulating the auditory nerves. One current prosthesis design includes an external transmitter and battery, and an internal receiver. The receiver interacts with electrodes that are surgically placed in the cochlea to allow selective stimulation of the cochlear wall (Hochmair et al., U.S. Pat. No. 4,284,856 and 4,357,497, incorporated herein by reference). The electrodes are typically contained in a substantially flexible electrode carrier having sufficient stiffness to be guided into the cochlea in the desired coiled shape (Hochmair-Desoyer et al., Annals of the New York Academy of Sciences 405:173-182 (1991), incorporated herein by reference).

Figure 1 shows a section view of an ear with a typical cochlear implant system. A normal ear transmits sounds through the outer ear **10** to the eardrum **12**, which moves the bones of the middle ear **14**, which in turn excites the cochlea **16**. The cochlea **16** includes an upper channel, known as the scala vestibuli **18**, and a lower channel, known as the scala tympani **20**, which are connected by the cochlear duct **22**. In response to received sounds transmitted by the middle ear **14**, the fluid filled scala vestibuli **18** and scala tympani **20** transmit waves, functioning as a transducer to generate electric pulses that are transmitted to the cochlear nerve **24**, and ultimately to the brain.

To overcome total sensorineural hearing loss, a cochlear implant system produces direct electrical stimulation of the cochlea **16**. A typical system may include an external microphone that provides an audio signal input to a signal processing stage (not shown) where various signal processing schemes can be implemented. For example, signal processing approaches that are well-known in the field of cochlear implants include continuous interleaved sampling (CIS) digital signal processing, channel specific sampling sequences (CSSS) digital signal processing (as described in co-pending U.S. patent application 09/648,68, filed August 25, 2000, and incorporated herein by reference), spectral peak (SPEAK) digital signal processing, and compressed analog (CA) signal processing. Typically, the processed signal is then converted into a digital data format, such as a sequence of data frames, for transmission into an implanted receiver **39**.

Besides getting the processed audio information to the implanted receiver **39**, existing cochlear implant systems also need to deliver electrical power from outside the body through the skin to satisfy the power requirements of the implanted portion of the system. Figure 1 shows an arrangement based on inductive coupling through the skin to transfer both the required electrical power and the processed audio information. As shown in Fig. 1, a primary coil **38** (connected to the external signal processor) is externally placed adjacent to a subcutaneous secondary coil **34** (connected to the receiver **39**). This arrangement inductively couples a radio frequency (rf) electrical signal to the receiver **39**.

The receiver **39** is able to extract both a power component from the rf signal it receives, and the audio information for the implanted portion of the system. Besides extracting the audio information, the receiver **39** also performs additional signal processing such as error correction, pulse formation, etc., and produces a stimulation pattern (based on the extracted audio information) that is sent through connected wires **44** to an implanted electrode carrier **46**. Typically, this electrode carrier **46** includes multiple electrodes on its surface that provide selective stimulation of the cochlea **16**.

The transmission rf signal for primary coil **38** is typically provided by a prominent behind-the-ear (BTE) module. This BTE module may also contain other system components such as the microphone and the external signal processing arrangement. The BTE module may be quite visually obtrusive, and it is known that some wearers of such devices are very sensitive that their appearance is abnormal.

Summary of the Invention

A representative embodiment of the present device includes a signal processing device for a cochlear implant. The device body fits into the ear canal of a user. The device body includes a microphone, a signal processor, and a transmitter. The microphone converts an acoustic signal present at the device body into a representative electrical signal. The signal processor performs signal processing of the representative electrical signal to form a cochlear implant signal. The transmitter converts the cochlear implant signal into a radio signal for transmission to a cochlear implant.

Another embodiment includes a cochlear implant system that has a signal processor that fits in the ear canal of a user. The signal processor processes an acoustic signal present in the ear of the user to produce a representative radio signal. A separate power transmitter transmits an electrical power signal through the skin of the user. A cochlear implant receives the radio signal and the electrical power signal and produces for the auditory nerve of the user an electrical stimulation signal representative of the acoustic signal.

In further embodiments, the device body may include a mechanical stimulation module that delivers to the inner ear structure of the user a mechanical stimulation signal representative of a portion of the acoustic signal. In such a device the cochlear implant signal is representative of a first subrange of frequencies in the acoustic signal, and the mechanical stimulation signal is representative of a second subrange of frequencies in the acoustic signal.

The processing performed by the signal processor may include at least one of compression, beamforming, and filtering. The signal processing may be continuous interleaved sampling (CIS) digital signal processing, channel specific sampling sequences (CSSS) digital signal processing, spectral peak (SPEAK) digital signal processing, or compressed analog (CA) signal processing.

An implanted battery module may power the cochlear implant, and the battery module may be rechargeable responsive to the transmitted electrical power signal.

The cochlear implant may use extracochlear electrodes to deliver the electrical stimulation signal. Alternatively, cochleostomy window associated electrodes may deliver the electrical stimulation signal. Or, multi-channel array electrodes may be partially or fully inserted into the cochlea of the user to deliver the electrical stimulation signal.

Another embodiment includes a cochlear implant system having a power transmitter that transmits an electrical power signal through the skin of the user, and a cochlear implant. The cochlear implant includes (i) a battery module that powers the cochlear implant, and that is rechargeable responsive to the transmitted electrical power signal, and (ii) a signal processor including a microphone. The signal processor processes an acoustic signal present in the ear of the user, and produces for the auditory nerve of the user an electrical stimulation signal representative of the acoustic signal.

Brief Description of the Drawings

The present invention will be more readily understood by reference to the following detailed description taken with the accompanying drawings, in which:

Figure 1 illustrates a section view of an ear connected to a cochlear implant system.

Figure 2 shows a top and a side view of an in-the-ear processor according to one specific embodiment of the present invention.

Detailed Description of Specific Embodiments

Various embodiments of the present invention are directed to a cochlear implant system that replaces the signal processing stage of the behind-the-ear (BTE) module of previous systems with an in-the-ear (ITE) module. This approach splits the power- and information-transfer functions to the implant into two independent transmission channels. Information transfer between the ITE processor and the implant uses a radio frequency (rf) connection. Power transfer uses the conventional inductively coupled coils. The transmitted power may be used to drive the implant, or implanted batteries may be recharged.

The ITE processor may be based on a conventional hearing aid, which is enhanced by an rf transmitter to communicate the audio information to the implant. Besides providing an audio signal to the implant for electrical stimulation of the auditory nerve, the ITE may also provide an acoustic mechanical stimulation module. This module can mechanically drive either the normal auditory chain of ear drum, middle ear, etc., or the round window from a cochleostomy. Such a combination of electric and mechanical auditory stimulation is described, for example, in application 09/258,997, filed February 26, 1999, which is commonly assigned and incorporated herein by reference. Combined electric and mechanical stimulation can be particularly effective in cochlear implant patients who retain some residual hearing. Typically, the electrical stimulation provides audio information in a first range of frequencies, e.g., higher frequencies, and the mechanical stimulation provides audio information in a second range of frequencies, e.g., lower frequencies.

Figure 2 shows a top and a side view of an in-the-ear processor according to one specific embodiment of the present invention. The ITE processor **50** looks like a conventional hearing aid that is inserted into the ear canal in the outer ear, **10** in Fig. 1. A tapered inner end **52** slides into the ear canal of the outer ear **10** until it mechanically engages the eardrum **12**. Figure 2 shows the tapered inner

end **52** as having a generic taper suitable for most users, but it is also known to make a custom molding of the ear canal of the outer ear **10** of the user, and to use this custom molding as the shape of the tapered inner end **52**. In an embodiment having an acoustic mechanical stimulation module, the mechanical drive signal may be provided via the tapered inner end **52**. Alternatively, the tapered end **52** may be adapted to mechanically drive the round window from a cochleostomy.

The ITE processor **50** contains conventional digitally programmable hearing aid processing circuitry for processing tasks such as compression, beamforming, filtering, remote control, etc. The outer end **54** of the ITE processor **50** may be adapted to have various user accessible controls as shown to provide some user control over the processing, and more generally, operation of the system. Also within the case of the ITE processor **50** are the rf transmitter and the battery.

To cooperate with the ITE processor **50**, the receiver, **39** in Fig. 1, contains signal processing circuits to receive and extract the rf audio information signals from the transmitter. The extracted audio information is then processed by the receiver **39** into electrode stimulation signals, which are communicated via connecting wires **44** to the implanted electrode carrier **46** to provide electrical stimulation to the cochlea **16**.

Various signal processing strategies are known in the art for stimulating the implanted electrodes in the electrode carrier **46**. These include continuous interleaved sampling (CIS), channel specific sampling sequences (CSSS), spectral peak (SPEAK), and compressed analog (CA) processing. Other processing and stimulation strategies are known, and new strategies are likely to be developed in the future; these are all within the scope of embodiments of the present invention.

Since both the ITE processor **50** and the receiver **39** contain signal processing components, specific embodiments vary as to how much processing is performed by each. For example, in a one system using CIS processing, the ITE processor **50** produces a minimally processed analog audio signal for the

subcutaneous receiver **39**. In other embodiments, the audio signal from the ITE processor **50**, while still analog, may have more sophisticated analog signal processing performed on it; for example, automatic gain control (AGC) and beamforming such as is done in a conventional hearing aid. Typical methods for transmitting an analog audio signal include well-known techniques such as amplitude modulation (AM) or frequency modulation (FM). In any case, the receiver **39** processes the received analog audio information using the CIS digital signal processing technique, and produces a stimulation signal for the electrodes of the implanted electrode carrier **46**.

But, in an alternative embodiment, the ITE processor **50** also may perform analog to digital conversion of the audio signal, followed by digital signal processing. For instance, the ITE processor **50** may transmit to the receiver **39** a sequence of digital data frames containing the information necessary to reconstruct the analog audio signal. Typical methods for transmitting a digital audio signal include such well-known techniques as amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). The receiver **39** may then perform CIS processing of the received digital signal and construct an electrode stimulation pattern based on the information in the received digital data signal. Alternatively, the ITE processor **50** may further process the digital audio signal to produce the CIS pulse information, which is then converted into a sequence of digital frames and transmitted to the receiver **39**. The receiver **39** then uses the information in the received digital frame sequence to construct the CIS pulse pattern for the implanted electrodes.

Similar shifting of signal processing functionality between the ITE processor **50** and the receiver **39** may be used in other specific embodiments based on other signal processing strategies. Moreover, the information channel to the receiver **39** can be used by other devices than the ITE processor **50**. For example, using the rf frequency of the receiver **39** and the proper audio information format,

a telephone, television, radio, or other external audio device could transmit an audio signal to the receiver **39**.

In representative embodiments, the receiver **39** may contain rechargeable batteries. With such an arrangement, a behind-the-ear (BTE) module may be used at night while the user is sleeping to inductively couple electrical power from primary coil **38** through the skin to secondary coil **34** to recharge the batteries in the receiver **39** while the user is asleep. Then, in the morning, the user can remove the BTE module and rely on the recharged batteries in the receiver **39** to provide electrical power throughout the day to the implanted portion of the system. Alternatively, a rechargeable battery module may be implanted separately from the receiver **39**. Using an implanted battery, there is no prominently visible external module, only the unobtrusive ITE processor, which appears to be a conventional hearing aid.

In another alternative embodiment, implanted rechargeable batteries are not used. Rather, the previously known inductive coupling arrangement is used to provide electrical power to the implanted portion of the system. And, if the all the signal processing is performed by the implanted portion of the system, the ITE processor may omitted altogether by also implanting a microphone in communication with the implanted receiver. Thus, power transmission and information transmission and processing are still kept as separate functions transmitted over separate channels. This arrangement allows for a low profile BTE module that may be covered by the user's hair, and which contains just an external battery and the power transmission components. These parts can be made to be very robust and inexpensive, and servicing is greatly simplified.

In another alternative embodiment, an external signal processing module may be added to the external part of the power transmission system. An rf receiver within this module receives and processes the audio information sent by the transmitter in the ITE processor. The processed audio is then modulated into

the power transmission signal, which has enough rf-bandwidth to transmit broadband stimulation data.

The foregoing discussion has described various advantages of representative embodiments of the present invention over existing cochlear implant systems that use an external BTE or body-worn processor. It should be noted that the various embodiments also offer significant advantages over fully implanted cochlear implant systems that have no external components. For example, the surgery to place the implanted portions of the system is less complicated than in a fully implanted system that surgically implants a microphone in the ear canal. Also, the location of the microphone in the ITE processor can be acoustically optimized compared to a system that integrates the microphone into the implant package. And, newly emerging signal processing strategies can be readily implemented in the ITE processor as they become available. This is not possible if the processing circuits are fully implanted.

Although various exemplary embodiments of the invention have been disclosed, it should be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the true scope of the invention.

What is claimed is:

1. A signal processing device for a cochlear implant, the device comprising:

a device body that fits into the ear canal of a user, the device body containing:

(i) a microphone that converts an acoustic signal present at the device body into a representative electrical signal;

(ii) a signal processor that performs signal processing of the representative electrical signal to form a cochlear implant signal; and

(iii) a transmitter that converts the cochlear implant signal into a radio signal for transmission to a cochlear implant.

2. A device according to claim 1, wherein the device body further includes:

a mechanical stimulation module that delivers to the inner ear structure of the user a mechanical stimulation signal representative of a portion of the acoustic signal,

wherein the cochlear implant signal is representative of a first subrange of frequencies in the acoustic signal, and the mechanical stimulation signal is representative of a second subrange of frequencies in the acoustic signal.

3. A device according to claim 1, wherein the processing performed by the signal processor includes at least one of compression, beamforming, and filtering.

4. A device according to claim 1, wherein the signal processing includes continuous interleaved sampling (CIS) digital signal processing.

5. A device according to claim 1, wherein the signal processing includes channel specific sampling sequences (CSSS).

6. A device according to claim 1, wherein the signal processing includes spectral peak (SPEAK) digital signal processing.

7. A device according to claim 1, wherein the signal processing includes compressed analog (CA) signal processing.

8. A cochlear implant system comprising:

a signal processor that fits in the ear canal of a user and processes an acoustic signal present in the ear of the user to produce a representative radio signal;

a power transmitter that transmits an electrical power signal through the skin of the user; and

a cochlear implant that receives the radio signal and the electrical power signal and produces for the auditory nerve of the user an electrical stimulation signal representative of the acoustic signal.

9. A system according to claim 8, wherein the signal processor further includes:

a mechanical stimulation module that delivers to the inner ear structure of the user a mechanical stimulation signal representative of a portion of the acoustic signal, wherein the cochlear implant signal is representative of a first subrange of frequencies in the acoustic signal, and the mechanical stimulation signal is representative of a second subrange of frequencies in the acoustic signal

10. A system according to claim 8, further comprising:

an implanted battery module that powers the cochlear implant, and that is rechargeable responsive to the transmitted electrical power

signal.

11. A system according to claim 8, wherein the processing performed by the signal processor includes at least one of compression, beamforming, and filtering.

12. A system according to claim 8, wherein the processing performed by the signal processor includes continuous interleaved sampling (CIS) digital signal processing.

13. A system according to claim 8, wherein the processing performed by the signal processor includes channel specific sampling sequences (CSSS).

14. A system according to claim 8, wherein the processing performed by the signal processor includes spectral peak (SPEAK) digital signal processing.

15. A system according to claim 8, wherein the processing performed by the signal processor includes compressed analog (CA) signal processing.

16. A system according to claim 8, wherein the cochlear implant uses extracochlear electrodes to deliver the electrical stimulation signal.

17. A system according to claim 8, wherein the cochlear implant uses cochleostomy window associated electrodes to deliver the electrical stimulation signal.

18. A system according to claim 8, wherein the cochlear implant uses multi-channel array electrodes partially inserted into the cochlea of the user to deliver the electrical stimulation signal.

19. A system according to claim 8, wherein the cochlear implant uses multi-

channel array electrodes fully inserted into the cochlea of the user to deliver the electrical stimulation signal.

20. A cochlear implant system comprising:

a power transmitter that continuously transmits an electrical power signal through the skin of the user; and

a cochlear implant having

(i) a power processing module that continuously provides power to the cochlear implant responsive to and representative of the transmitted electrical power signal, and

(ii) a signal processor including a microphone, the signal processor processing an acoustic signal present in the ear of the user and producing for the auditory nerve of the user an electrical stimulation signal representative of the acoustic signal.

21. A system according to claim 20, wherein the processing performed by the signal processor includes at least one of compression, beamforming, and filtering.

22. A system according to claim 20, wherein the processing performed by the signal processor includes continuous interleaved sampling (CIS) digital signal processing.

23. A system according to claim 20, wherein the processing performed by the signal processor includes channel specific sampling sequences (CSSS).

24. A system according to claim 20, wherein the processing performed by the signal processor includes spectral peak (SPEAK) digital signal processing.

25. A system according to claim 20, wherein the processing performed by the signal processor includes compressed analog (CA) signal processing.

26. A system according to claim 20, wherein the cochlear implant uses extracochlear electrodes to deliver the electrical stimulation signal.

27. A system according to claim 20, wherein the cochlear implant uses cochleostomy window associated electrodes to deliver the electrical stimulation signal.

28. A system according to claim 20, wherein the cochlear implant uses multi-channel array electrodes partially inserted into the cochlea of the user to deliver the electrical stimulation signal.

29. A system according to claim 20, wherein the cochlear implant uses multi-channel array electrodes fully inserted into the cochlea of the user to deliver the electrical stimulation signal.

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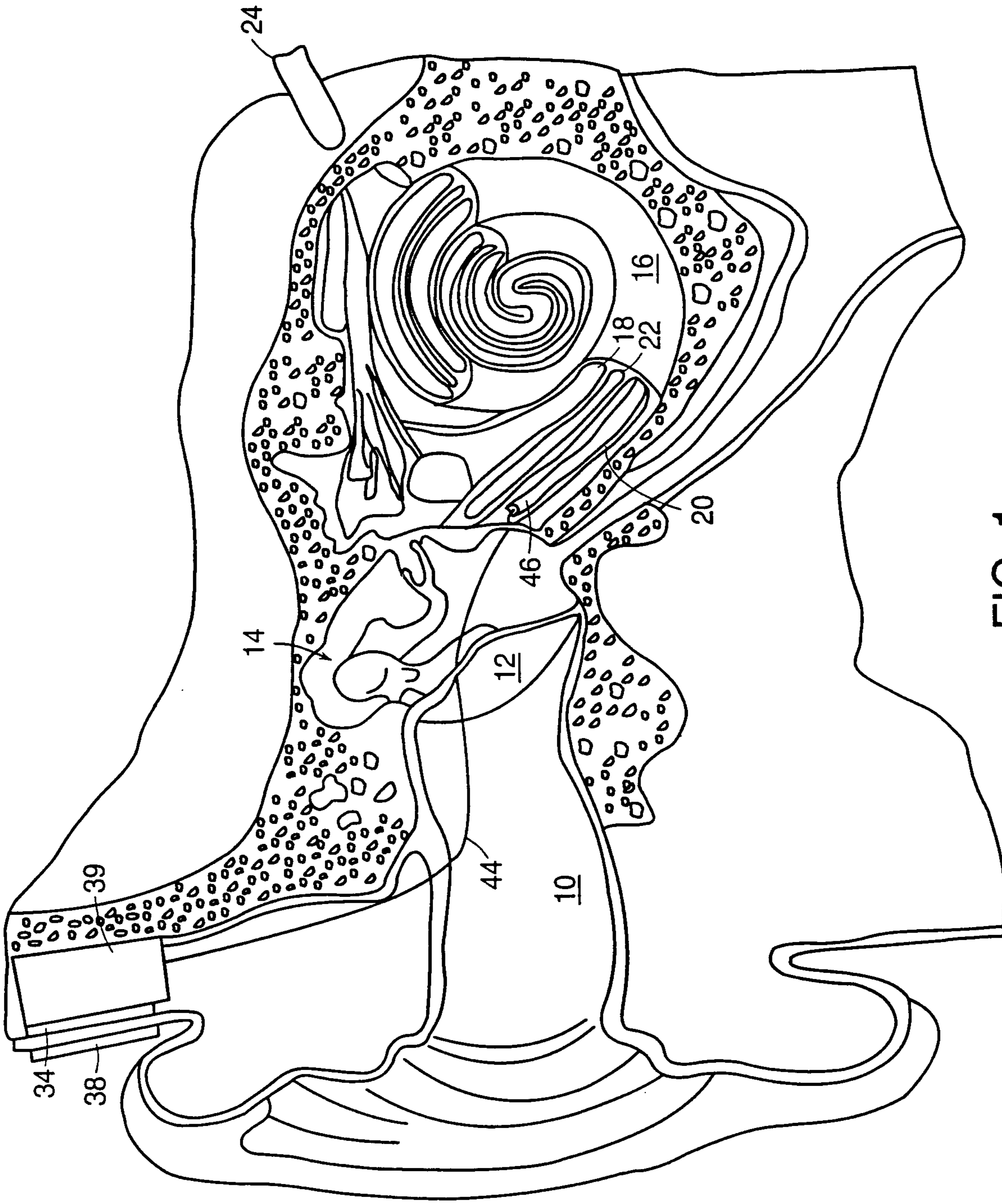

FIG. 1

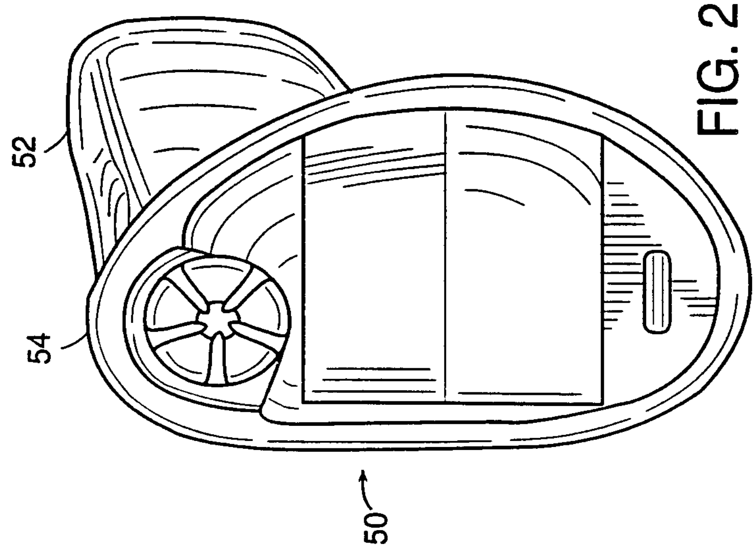

FIG. 2B

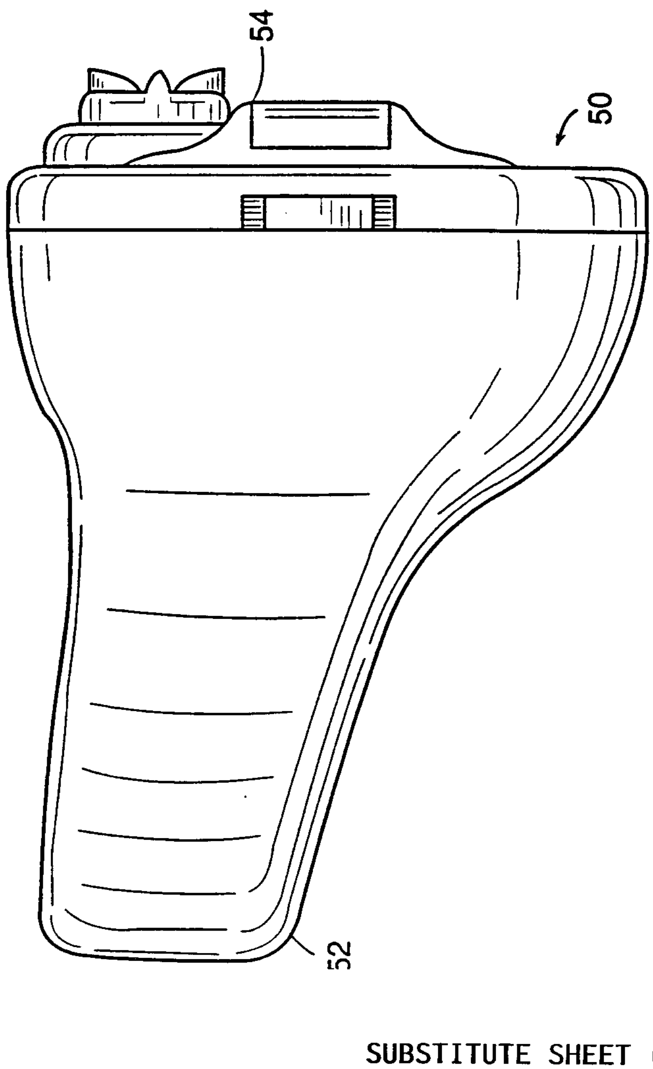

FIG. 2A

INTERNATIONAL SEARCH REPORT

In ational Application No
PCT/IB 01/00455

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61F11/04 A61N1/36 H04R25/00 H04R25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61F A61N H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
15 June 2001	27/06/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Kuehne, H-C

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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